Stirred milling—new comminution technology in the PGM industry

by C.M. Rule*

Synopsis

Stirred milling using either horizontal or vertical mills has made a rapid entrance into PGM ore and tailings concentrator flow sheets. Currently there are in excess of 40 units installed in either mainstream, 'MIG' or intermediate concentrate regrind, 'UFG', applications in PGM, primary ore treatment plants or in tailings scavenging and reclamation treatment plants. This represents a total of approximately 70 MW of installed fine grinding equipment. This paper outlines the reasons why the technology take-up has been rapid and illustrates the advantages of this technology over conventional milling.

Keywords

PGM, platinum group metals, UG2, Merensky, platreef, stirred milling, MIG—mainstream inert grinding, UFG—ultra fine grinding of intermediate flotation concentrates, IsaMill™, Metso SMD™, Deswik, ceremic grinding media, QEMSEM, MLA.

Introduction

Stirred milling is the latest comminution technology to be applied widely in the PGM industry. The drivers for this are related to the shift in the mining and extraction of PGMs from the Bushveld from Merensky reef to the UG2 and Platreef orebodies; (Figure 1) the expansion of the production base; extraction of PGMs from tailings in both PGM and chromite primary production; and the recent major increase in the diversity of companies involved in the PGM production process.

The first stirred mill in the PGM industry was installed at Lonmin Eastern Platinum in 2002 when a 3 000 litre IsaMill™ in a cleaner tails regrind was installed at the 'C' section concentrator; this was followed by the WLTR, 10 000 litre IsaMill™ rougher scavenger flotation concentrate regrind installation of Anglo Platinum in 2003[1].

There are now multiple installations of the technology throughout South Africa. A total of >40 vertical and horizontal stirred mills are now installed with an estimated >70 MW of drive power. Individual units in commercial PGM production range in size from 18.5 kW to 3 000 kW. Anglo Platinum has installed the major portion of this capacity, with 23 units and 64.5 MW of installed drive power[2,3]. The technology can be simply said to be used for two main process duties. The terminology to differentiate the two applications being used by Anglo Platinum is:

➤ MIG or mainstream inert grinding—so named to indicate the 'mainstream' application in the process flow, the target grinds are typically 80%–45 microns at the finest level and the 'inert' or non steel media 'grinding' environment

➤ UFG or ultra fine grinding—the conventional mining industry term for intermediate flotation concentrate regrinding; typically producing products at P80 grinds of less than 20 microns and even to less than 10 microns and finer.

The use of this technology requires a suitable and economic grinding media; initially low cost media have been employed—sized silica or river sand and granulated furnace slag. This is now becoming more uncommon with ceramic grinding media of various compositions being generally employed. Efficiency of operation, stirred mill type, and quality control are important factors in this selection of media; but the major reason has been the relative hardness compared to feed materials in MIG stirred milling installations.

Stirred milling technology

Background

Stirred milling technology has been a common size reduction technique employed in a myriad industries for many years. Good examples are in the titanium pigment, paper/plastic filler

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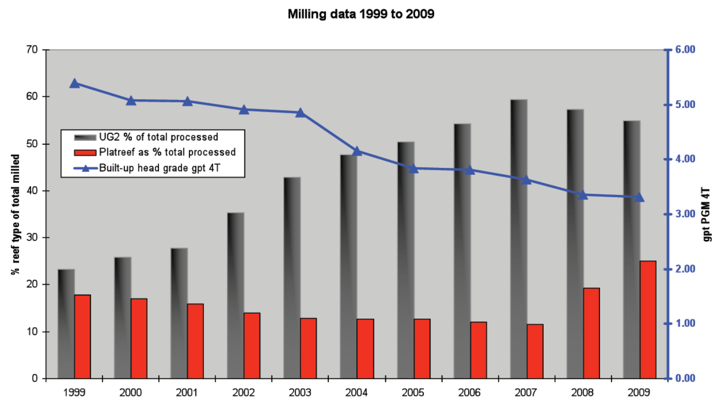

Figure 1—Graph of relative proportions of PGM reefs mined by Anglo Platinum over the period 1999 to 2009; reduction in higher grade Merensky is inferred from growing proportions of UG2 and Platreef

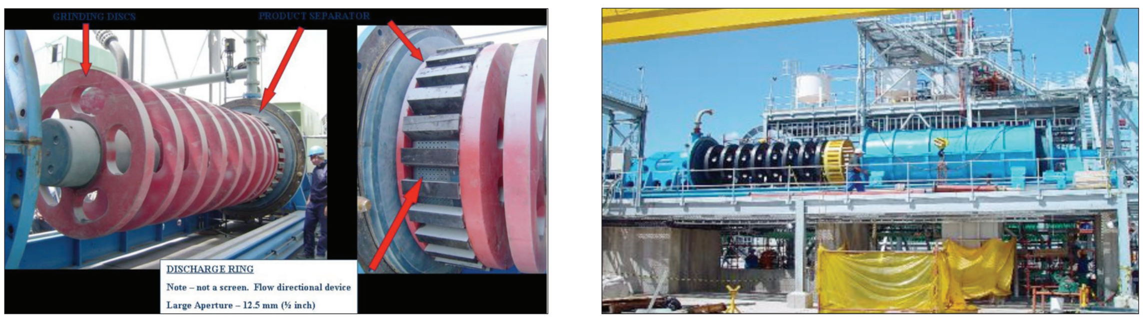

Figure 2—Layout and Internal arrangements of a large-scale IsaMill**

Figure 3—Vertical stirred mills (Deswik and Metso SMD**)

production processes; ultra fine grinding of industrial minerals; and in the pharmaceutical, food, printing inks, ceramic and chemical industries.

The first applications of stirred mills in the metals mining industry occurred in the lead and zinc industry with the development of the IsaMill™ technology by MIM, now Xstrata Technology, in the late 1980s (Figure 2). The first four commercial 3 000-litre mills were installed in flotation concentrate regrind applications at MIM's, now Xstrata's, Mt Isa lead/zinc concentrator in 1995[4–6].

In 1998/9, multiple vertical stirred mills, were installed at the then Pasminco's, Elura and Century Zinc Operations; these Metso SMD™ units were used to regrind flotation concentrates.

The IsaMill™ technology development has been well documented as has that of the SMD™ at the Century and Elura operations[7–9]. The original technologies had emanated in the industrial and other fine grinding industries; IsaMill™ technology developed by Xstrata Technology with long-term fine grinding technology supplier, Netzsch Feinmahltechnik GmbH and the Metso SMD™ technology from development initially at English China Clays (now Imerys), where multiple units had been installed since the 1980s (Figure 3).

Mineralogy of PGMs

The basic reason why stirred milling has appeared in the PGM industry is linked to the mineralogy of the primary ore deposits. PGMs occur in the Bushveld in several exploited reef horizons; the first three exploited for PGM production:

- Merensky Reef
- UG2 Reef
- Platreef.

MG1 and 2 and LG6 chromitite reefs are exploited for extraction of chromite products.

The PGM values in the reefs vary in form, particle size, mineral speciation and association. Historically the Merensky Reef was exploited; only from the 1970s was the UG2 Reef brought into commercial production, and since 1990s the Platreef has been exploited.

Satisfactory PGM extraction efficiencies, typically 80–90% of concentrator plant feeds were achieved in the Merensky Reef concentrators. The available comminution technology, and indeed the economics of pursuing further recovery by finer grinding, were not compelling.

It is interesting to note that mineralogical techniques to easily quantify PGM losses to plant tails were not available prior to the last two decades. For Merensky, the use of the QemSem hardware/software, an automated scanning electron microscope system, was limited in its PGM mineral search and quantification ability and was focused on sulphides mineral species analyses. This in the recent past fitted the requirements of the Merensky Reef dominated industry.

As UG2 and then Platreef became more and more important as a source of commercial PGM production at the expense of Merensky Reef, this situation changed. Since 2000, all three major producers, Anglo Platinum, Impala Platinum and Lonmin Platinum, have moved increasingly into mining the UG2 Reef horizon. All the second tier producers that have started new mining operations have done so on the UG2 Reef horizon. PGM recoveries were typically significantly lower and came with the chromite content issues in smelter feedstock produced in conventional Merensky flowsheets adapted for UG2 concentrator processing. The need to understand the PGM loss to concentrator tails profile had become a huge opportunity[10]. This changing scene also applied to the complex mineralogy of the Platreef where ore quality and extraction efficiencies are highly variable.

PGM occurrence in the UG2 Reef and Platreef has been the focus of intense study at Anglo Platinum; and with the advances in mineralogical hardware, the scope of what is possible has grown immeasurably. Understanding the ore's PGM speciation and association has led to the focused pursuit of new technologies to increase metallurgical efficiencies.

Thus the macro environment has made this a compelling initiative:

- Higher PGM basket pricing
- More complex and difficult mineralogy
- Lower mined grades to the plant and higher relative costs of extraction from increasingly deeper underground PGM mining.

Figure 4 illustrates typical UG2 mineralogical data from analyses by MLA techniques; it graphically illustrates the recovery of liberated PGMs and sulphides to final product, (green and yellow shading) and due to incomplete liberation the loss association profile in final tailings—mostly middlings and locked PGMs in silicates, shaded as grey colours.

The data presented in Table I for a different set of monthly composites from another UG2 plant show another interesting feature. It can be easily seen that there is a high proportion of incompletely liberated PGMs in the final flotation concentrate. This indicates the potential for concentrate regrind technology not only to improve final product grade but also, by changing the grade-recovery relationship, to improve in overall PGM recovery.

The particle size of the PGMs is shown in Table II. The interest in mainstream fine grinding, MIG and ultra fine grinding of primary flotation concentrates, UFG is easily illustrated. The tailings average particle size at an estimated P50 of 5.5 microns illustrates the potential liberation problem if these PGMs are disassociated from sulphides and are associated only with silicates.

Two of the major differences between ore types directly related to plant recovery achieved are (1) particle size of the PGMs and (2) their association with sulphides or with

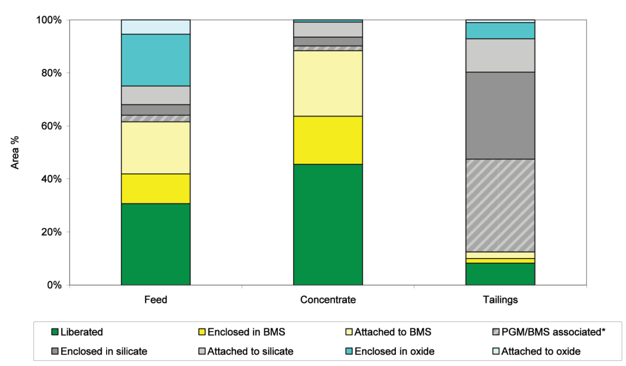

Figure 4—Typical association data for a UG2 primary mill product, final flotation concentrate and final tailings

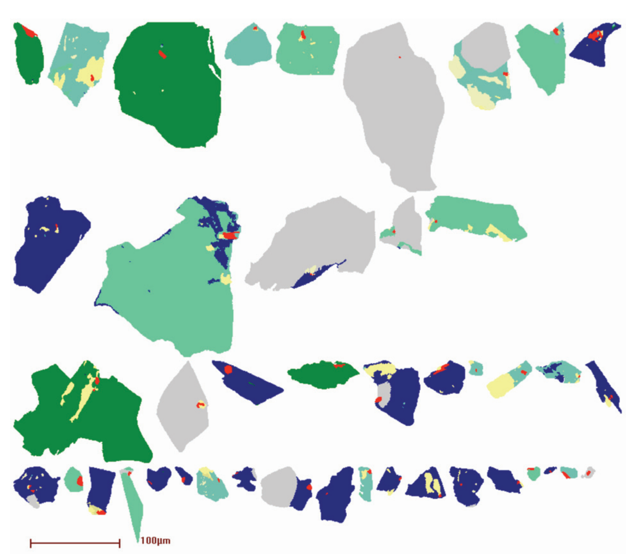

Figure 5—False colour photomicrographs of PGM bearing particles in a typical PGM tailings sample; note the 100 micron bar to show relative sizes. Red colouration shows PGMs, yellow shades the sulphides, green shades silicates, and blue shades oxides

Table I

PGM association data for a typical UG2 plant composite set*

	Feed	Concentrate	Tailings
Liberated	30.7	45.4	8.3
Middlings	3.4	26.8	1.0
Locked	65.9	27.7	90.7
Total	100.0	100.0	100.0

*Showing preponderance of incompletely liberated PGMs in the tailings; these results are slightly atypical in that majority of PGMs recovered are as middlings and locked particles in the final concentrate

Table II

The particle size % distribution for PGMs by size fraction for typical UG2 monthly plant composites

	Feed	Concentrate	Tailings
<4.1	22.3	20.8	34.8
5.7	14.4	12.2	16.9
9.6	23.1	18.6	36.2
13.5	4.4	11.6	12.1
19	14.4	7.3	
27	8.5	0.0	
38	12.9	4.9	
53		24.6	
Total	100.0	100.0	100.0
P50	7.5	9.2	5.5

silicates as either locked or middlings particles. The relatively better commercial plant metallurgical performance of the Merensky Reef compared to most UG2s and the Platreef is easily explained by these differences. Further, UG2 Reef variability in metallurgical performance is normally illustrated by differences in these properties, especially when the degree of silicate association is considered. Simply, a 'metallurgically poor UG2 ore' performance is usually associated with a higher degree of silica associated PGMs and increased tailings PGM losses due to incomplete liberation.

This size-association relationship is illustrated well in Figure 5—very small PGMs and sulphides are often locked in composite particles. Recovery to final product can only be by entrainment or by improved comminution and liberation to higher grade middlings or fully liberated particles.

The typical UG2 tailings analyses of size of PGMs contained in composites in the various size fractions in tailings typically shows the opportunity to improve liberation and hence recovery of the valuable minerals (Figure 6). The potential for improvement in PGM recovery by better liberation is again easily seen. Mainstream inert regrind or MIG technology is addressed at this PGM loss. In the UG2 circuits of Anglo Platinum the MIG IsaMill™ technology currently targets silicate associated PGMs contained as composites and aims for target grinds of 80%–53 microns[11].

One of the features of the IsaMill operation is the minimization of super fines, i.e. < 5 microns due to the low average particle mill residence time and enhanced attrition grinding action. The preferential grinding at the coarse end of a typical feed stream particle size distribution is beneficial. The use of inert grinding media—ceramics as opposed to steel grinding media—preventing iron hydroxide coating of particles for coating fine particles with iron hydroxides, a well-known phenomena in steel ball grinding systems.

Current status of stirred milling in South African PGM industry

Table III shows the installations currently in the PGMs and PGMs from chromite industry. A total of more than 70 MW has been installed in recent years. The first mill started operation in 2002. Subsequently they have been installed at an increasing pace in both PGM concentrator operations and in PGM recovery from PGM tailings and in chromite tailings dumps and current arisings.

The use of small vertical stirred mills employing ceramic media in tailings recovery operations was pioneered at Platinum Mile in 2007; currently 6 mills are employed at two

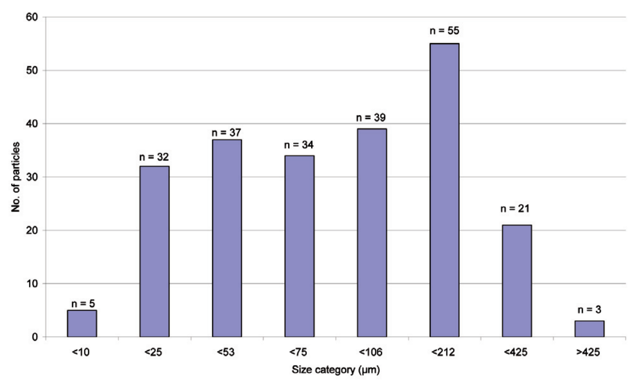

Figure 6—Typical UG2 tailings monthly composite sample, showing the size fraction by size fraction count for composite particles, locked, or middling PGMs in silicates/oxides

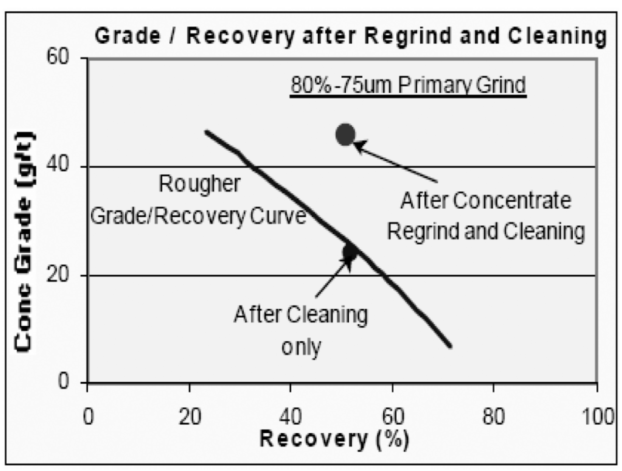

Figure 7—The improvement in PGM grade/recovery by employing stirred milling in an UFG application was incorporated into the WLTR project in Rustenburg

of these operations. Their purpose is to enhance recovery of PGMs at an acceptable PGM final flotation product grade for downstream smelting. By significantly changing the grade-recovery relationship, this can be achieved very successfully. Feeds to these plants are typically less than 1 gpt PGMs and products must normally be >50 gpt PGMs; that is a very low mass pull is, targeted.

A further application of stirred milling—again done with vertical mills—is the preparation of feed to flotation in the chrome recovery plants that have sprung up on the Western and Eastern Bushveld. A total of at least eight of these plants are now in operation, treating both the current spiral tailings from existing chromite product concentrator plants and also the accumulated tailings from these operations. Feed grade is generally in the 2–4 gpt PGM range. Stirred milling has been reportedly key in attaining much improved PGM recoveries, sometimes in excess of 50%. In most of these plants very small vertical stirred mills are employed to condition the rougher flotation concentrates to improve the grade-recovery relationship and produce better products for PGM smelting.

Table III shows the current situation of installed stirred mills in both the PGM industry and the PGMs from chromite tailings industry.

Development of stirred milling—Anglo Platinum

Evaluation of stirred mill technology began in 2000 at Anglo Platinum using a laboratory size Metso SMD™ and the 4-litre laboratory IsaMill™ at both the Anglo Platinum Research Centre facilities at Germiston and Rustenburg. Various ores and sampled process streams were tested, including UG2, Merensky and Platreef and cleaner tailings and final tailings. Promising results were seen on all tests, with an improvement in the PGM grade-recovery relationship seen with stirred milling. Larger-scale IsaMills were installed at the Rustenburg pilot plant and a full-scale evaluation on dormant tailings containing low PGM values from the Rustenburg and Union mining areas was conducted. The results were sufficiently promising in both grade-recovery relationship improvement on rougher concentrate feed and also on mainstream tails reduction to consider using the technology. The opportunity to include the IsaMill™ stirred mill technology in the process flowsheet of the phase 1 WLTR project was taken.

Significantly, the decision to scale up the 1 MW 3000-litre commercial unit was made to make mainstream IsaMill™ applications in the future more attractive. Working with Xstrata Technology and the manufacturers Netzsch Feinmahltechnik GmbH of Germany, the result was a 10 000-litre unit with a variable speed drive of 2 600 kW. The drive was chosen to allow mitigation of potential internal separator performance risk. Silica sand crushed and screened was chosen as low cost media for concentrate regrinding applications (Figure 8).

This mill was commissioned in late 2003 and delivered its expected metallurgical performance, allowing final product grades at the expected range of PGM recovery. Importantly, the scale-up was almost perfect, and indeed it soon became apparent that operating costs and efficiencies were improved compared to the M3000 unit installed in a similar UFG application in the PGM industry at Lonmin in 2002.

The foundation had thus been laid for a wider adoption of the technology in Anglo Platinum concentrator plants.

A comprehensive testing process had been initiated from 2004 on various streams taken directly from the process at all the group Concentrators. This on site pilot testing used a

Table III

Total installed base of stirred mills in South Africa, PGMs and PGMs from chromite operations

Operator	Operation	Number of stirred mills	Type	Installed power kW	Application
		PGM concentrators			
Anglo Platinum/JVs	WLTR	1	IsaMill™M10000	2600	UFG/MIG
	Waterval UG2	2	IsaMill™M10000	6000	MIG
	Mogalakwena South	3	IsaMill™M10000	9000	MIG
	Mogalakwena North	4	IsaMill™M10000	12000	MIG
	Waterval	4	IsaMill™M10000	12000	MIG
	Amandelbult	4	IsaMill™M10000	12000	MIG
	Amandelbult	1	IsaMill™M3000	1500	UFG
	Mogalkwena North	1	IsaMill™M10000	3000	UFG
	Waterval	1	IsaMill™M10000	3000	UFG
	Mototolo	1	Metso SMD™355	355	UFG
RBR	BRPM	1	IsaMill™M10000	3000	MIG
Lonmin	Eastern Platinum C	1	IsaMill™M3000	1000	UFG
	Eastern Platinum A/B	1	Metso SMD™355	355	UFG
Platmin	Boynton	1	IsaMill™M3000	1500	MIG
		PGM tailings retreatment			
Impala	Rustenburg TRP	2	Metso SMD™355	710	UFG
Platinum Mile	Paardekraal TRP	2	Metso SMD™355	710	UFG
	Paardekraal TRP	2	Deswik-2000 litre	1065	UFG/MIG
		Chromite tailings retreatment			
Aquarius/JV	RK1 chromite tails	1	Deswik-1000 litre	500	MIG
Sylvania	Steelpoort	2	Metso SMD™185/18.5	203.5	UFG/MIG
	Lannex	1	Metso SMD™185/18.5	185	UFG/MIG
	Lannex	1	Kings	75	MIG
	Milsell	2	Metso SMD™185/18.5	203.5	UFG/MIG
Tharisa	Brits Chrome TRP	1	Deswik-500 Litre	220	MIG

Figure 8—Photograph illustrates the scale-up of IsaMill** technology; M1000, M3000 and M10000 mills: M3000 initially at Mt Isa Mines (1995), and the first M10000 at Anglo Platinum's WLTR plant (2003)

20-litre IsaMill™ coupled with a 'fctr' flotation test unit to assess performance change with regrind stirred milling using initially silica sand but later using ceramic grinding beads.

In parallel, a comprehensive monthly composite fractional analysis both by assay and mineralogy was embarked on to provide supporting ore characterization data on each concentrator plant. Resulting from this work programme a decision was made in 2005 to install what would become the first mainstream IsaMill™ installation at Mogalakwena South 'C' section. This mill would regrind secondary ball mill product prior to scavenger rougher flotation and employed the newly available zirconia toughened alumina ceramic grinding media. The drive was increased to 3 000 kW; the media specific gravity was 3.75 g/cm^3. Commissioned in late 2006, the mill soon demonstrated significantly improved PGM recoveries in comparison to the other two processing modules in the plant, sections A and B (Figure 9).

Based on economic priorities, a further two mainstream applications were approved in 2006; four more 10 000-litre 3000 kW IsaMill™ were commissioned in late 2007—two at Waterval UG2 and Mogalakwena sections 'A' and 'B'. The next wave of installations was approved that year and a further 16 IsaMill™ were ordered for installation at BRPM, Waterval, Amandelbult and the new Mogalakwena concentrator.

At this point, to avoid project and operating confusion, the nomenclature for mainstream mills, MIG, mainstream inert grinding and concentrate regrind mills, UFG, ultra fine grinding was adopted. This recognized the unique mainstream application and significantly the non-steel media grinding environment.

UFG applications number more than 12, some in PGM concentrators, 4 at Anglo Platinum, 2 at Lonmin, 5 employed in PGM tailings scavenging plants, 3 at Platinum Mile 12, and 2 at Impala; the rest are used in PGMs recovery from chromite dumps/current tailings – see Table III.

In 2009 all 16 of these mills were commissioned in 9 months on the four sites; in addition, learnings and improvements in the circuit operating set-up and equipment and flow design were incorporated into all 22 IsaMill™ circuits, with the 5 initial mill circuits being recommissioned with the improvements to the circuit, over the same time period. At Mototolo Concentrator, a 355 kW Metso SMD™ was installed on an intermediate concentrate regrind, UFG in 3Q 2009. Thus by year end Anglo Platinum had 23 stirred mills in operation, 18 in MIG and 5 in conventional UFG duties at various concentrator plants treating UG2, Merensky, mixed ore and Platreef.

Early operational results have vindicated the aggressive roll-out decision, with improved metallurgy evident at all sites. Importantly, learning from operational experience and circuit optimization, operating costs for all units have been reduced progressively since start-up. Early premature wear component failures and high wear rates have been eliminated entirely.

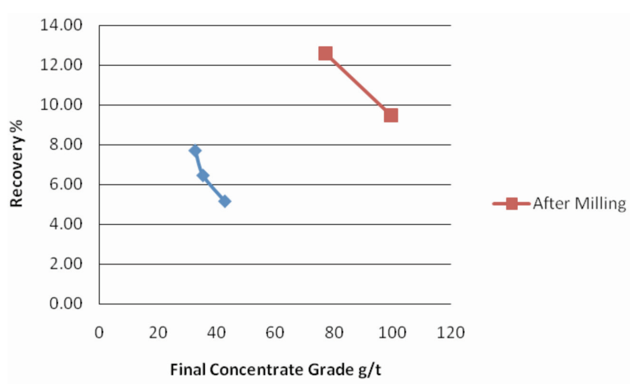

Figure 10—PGM grade-recovery pre- and post-UFG with vertical stirred milling at tailings retreatment operation, courtesy of Platinum Mile

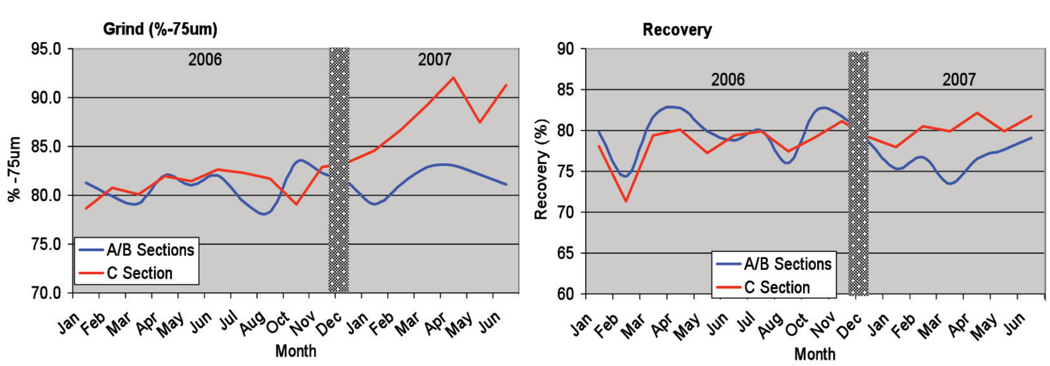

Figure 9—Graphs showing relative performance of Mogalakwena South C section with first MIG IsaMill** compared to the other two sections at the South concentrator

Development of ceramic media

A critical part of the roll-out of the stirred milling projects has been the development of a structured ceramic media development programme. This was a requirement of the initial MIG project approval in 2005.

Ball milling using steel media or tower milling using steel media have been widely used for fine grinding—i.e. less than 75 microns P80—and for concentrate regrind for many years in most of the metals industry. The economics of using ball milling for finer and finer grinding have been a barrier to achieving very fine grinds.

Ceramic media as opposed to using steel grinding media for fine milling, have major potential metallurgical benefits. Using ceramic media instead of steel media will result in minimization of the release of iron into solution and the precipitation/adsorbtion of iron hydroxides onto valuable mineral surfaces, thus affecting flotation recovery[13–16]. Further, the intense attritioning environment in a stirred mill with ceramic grinding media would also have positive impacts due to surface cleaning—removing coatings and iron hydroxides present form upstream comminution with steel media.

Anglo Platinum has established a ceramic media testing and QA/QC control protocol centred on the Divisional Metallurgy Laboratory, DML, facilities at Rustenburg[17]. The facilities include testing of ceramic medias on water and slurries at 4 litre and 100 litre IsaMill™ scale and ceramic media characterization and testing equipment.

This involved approach, which could be termed becoming an 'expert user', has allowed extensive and meaningful engagement to be made with the worldwide supplier base. This has led to an understanding of the ceramic media market and a consequent and very significant drop in the operating cost associated with ceramic media for stirred milling operations.

Impacts on the overall processing flowsheet

The move to progressively finer grinds may have impacts on other parts of the flowsheet of the concentrator and indeed on the downstream processes, e.g. tailings dams and smelting operations.

Early assessments of the impacts of both finer mainstream and final flotation product grinds have not led to major operational issues to date. Existing technologies employed in tailings[18] and filtration[19] operations are able to cope with the finer products presented.

Conclusion

Stirred milling has already shown its ability to significantly improve metallurgical performance in the flowsheets it has been incorporated into in the PGM industry. Its potential has more than likely not been fully seen due to the short operating period of the majority of the installations. The small size of PGM particles and their association with silicate gangue has always been an obstacle to getting high metallurgical extractions through conventional milling and flotation circuits. Stirred milling technology has offered a route to improved recovery by grinding finer economically, and also brings the benefits of an 'inert' grinding environment without the use of steel grinding media.

Acknowledgements:

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